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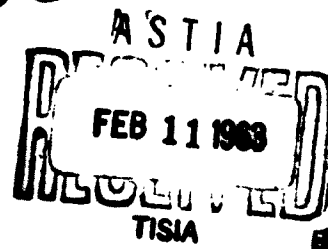
AN EXPERIMENT IN USING THE ELECTRONIC COMPUTER
"STRELA" FOR PROCESSING MEASUREMENTS OF METEORIC
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AN EXPERIMENT IN USING THE ELECTRONIC
COMPUTER "STRELA" FOR PROCESSING
MEASUREMENTS OF METEORIC PHOTOGRAPHS

A. K. Sosnova

The processing of measurements of meteor photographs is very laborious.

We made an attempt to use the electronic computer "Strela" for the calculation.

"Strela" is directed by programming and automatically solves problems reduced to a definite sequence of arithmetical and logical operations*. In the machine numbers are represented and calculations with them are carried out with 35 binary symbols (significant numbers) with a floating decimal. The range of numbers used is $\pm 10^{\pm 10} (\pm 2^{\pm 32})$.

A three-address system of instructions and a parallel means of storing, transmitting, and converting numbers and instructions characterize the machine; calculations are done in the binary system; the conversion of the initial numerical data from the decimal to the binary system and the reverse conversion of the output is accomplished

*A. I. Kitov. Electronic Computers. Izd. "Sovetskoe Radio." Moscow, 1956.

automatically by the machine.

Before proceeding to solve any problem on the machine, one sets up a schedule according to the chosen method of numerical solution. The numerical method is chosen so as to use the simplest and most uniform formulas, although in doing so it is often necessary to sacrifice the required accuracy for an increase in the scope of the calculations.

The method must reduce the solution to elementary operations and provide control of the solution.

Into the flow pattern of each problem there enters a sequence of arithmetical operations, of provisory and absolute transfers of control, of change and renewal of instructions.

The complete program of the solution is formed in conformity with the flow pattern and the earlier made distribution of the data in the registers of the machine.

The program for solving the problem written in the form of a system of instructions and the initial numerical data are entered on punch cards. Each number or instruction is recorded on one line of a standard 80-column punch card with a certain combination of holes.

The numbers and instructions are put into the codes with which the machine operates. Each code contains 42 binary digits.

The numbers are presented in semilogarithmic form: each number N is represented in the form of 2 groups of digits—a mantissa and an ordinate

$$N_{10} = d \cdot 10^p, \quad 0.1 \leq d < 1,$$

where mantissa d is the sequence of the digits representing the number and the ordinate p indicates between which numbers of the mantissa the decimal belongs.

Every decimal digit of a number N in the machine is represented in the binary system (binary-decimal numbers). The signs of the numbers in the machine are plus-zero and minus-unity in the number set aside for the sign.

If we examine the code as an instruction, it consists of the following parts: 1st, 2nd, 3rd address, control signal, and number of operation to be carried out.

In the 1st and 2nd addresses the instructions indicate the number of compartments from which the numbers are taken on which are to be performed the operation indicated by its own number; the 3rd address indicates the compartment into which the number obtained from the operation is to be placed.

Before solving a problem a pack of punch cards with the program and initial data are fed into the machine.

The work of the machine consists in sequential execution of the instructions in the program.

The results of the solution are fed out of the machine onto punch cards and are printed in the form of tables of numbers in the order predetermined by the program.

In the MGU "Strela 4" electronic computation center we composed and debugged a program for processing photographic observations of meteors.

We present below the method of deriving the initial data and the flow pattern of the calculations according to which the program was composed.

Derivation of initial data. We will designate the point of observation at which the shutter was fixed as A, and, correspondingly, we will call the negative interruptedly tracking the meteor negative A.

We will designate a corresponding point as B and the negative obtained there we will call negative B. We will adopt point A as the base point and in respect to it we will determine the heights H_m and velocities V_m of the points of the meteor, as well as the distance from the zenith, z_m , and the radian distance, z_R (we are assuming that the negatives are made in guided cameras).

The choice of reference stars. Reference stars are selected, up to 12 and not less than 6, uniformly along the course of the meteor and on both sides of it on each negative, and one star not farther than 1° from its optical center. (For NAFA 3C/25 factory-produced cameras we may take the intersection of the two diagonals of the frame as the optical center.)

It is desirable that the reference stars be of the same magnitude. It is better to take those of the 8th-9th magnitude as references for guided cameras and those of the 6th-8th magnitude for non-guided cameras.

The equatorial coordinates of the stars are written out for the equinoctial time of observing the meteor from AGK₂ or the Yale Catalogue with an accuracy of $0.01''$ for α and $0.1''$ for δ (the time is accurate to 0.1 of a year).

Measurements. The plate (or the film frame between two pieces of glass) is oriented in a measuring machine so that one of the axes of the device, we shall call it the x axis, is directed along the meteor's trail.

On plate A are measured x and y for the reference stars and the star taken as the optical center, for 16 points uniformly spaced along the trail of the meteor, and for the ends (or mid-points) of the gaps in the trail. The x and y coordinates of the 16 points are subsequently used for finding the equatorial coordinates of the pole of the meteoric

circle; and the \underline{x} and \underline{y} coordinates of the ends (or mid-points) of the gaps, for determining heights and velocities.

On plate B are measured the \underline{x} and \underline{y} coordinates of the reference stars, of the star taken as the optical center, and of the 16 points along the meteor's track.

In order to avoid the effect of a possible movement of the plate in measuring it is best to proceed as follows: measure first the coordinates of the stars, then of the points along the meteor's trail, and finally the coordinates of several stars again. If the first and last measured coordinates of the same stars coincide (within the limits of measurement error, i.e., $2-3\mu$) we may consider that the plate did not move.

In order to exclude systematic errors the measurements are made with a reversing prism or by turning the plate 180° .

Two applications each of the cross hairs of the measuring instrument are made for each measured object in one position of the prism or plate.

For our calculations it is necessary to have the following values:

- a) for the 12 reference stars - equatorial coordinates α_0, δ_1 and the measured coordinates \bar{x}_1, \bar{y}_1 ;
- b) for the optical center stars - equatorial coordinates α_0, δ_0 ; the measured coordinates x_0, y_0 ;
- c) for the 16 points along the meteor's trail - the measured coordinates \bar{x}_k, \bar{y}_k ;
(values a, b, and c are necessary for both plates A and B);
- d) for the 20 points at the ends (or mid-points) of the gaps in the meteor's track on plate A - the measured coordinates \bar{x}_m, \bar{y}_m , and the times τ_m corresponding to each of these 20 points (τ_m prefigured

from the known closing speed of the shutter);

e) there must also be given the latitude φ of point A ($\sin \varphi$, $\cos \varphi$) and data on the base: hour angle and declination t_b , δ_b of the bearing of the base line and the length of the base b in km; and for directional cameras the sidereal time S of the appearance of the meteor (exactly determined).

For a given base of observation φ , b , t_b , and δ_b are constant.

The program of calculations is figured for the 12 reference stars, 16 base stars, and 20 end points of the gaps in the meteor's track.

The calculations may be carried out also for a smaller number of reference stars and points along the meteor's trail (but this number must not fall below 6).

In addition, five more values must be given:

f) a number one less than the number of reference stars for plate A, i_A-1 , and the same for plate B, i_B-1 (the center-point star is left out of consideration);

a number one less than the number of base points along the meteor's trail on plate A, k_A-1 ; and the same for plate B, k_B-1 ;

a number one less than the number of end (mid) points in the trail gaps on plate A, m_A-1 .

All the initial data enumerated above, beginning with item (a) are put on punch cards and these are fed into the machine to execute the calculations.

The coordinates of the poles of the meteor great circles A and B and the coordinates of the radiant; the heights, velocities, decelerations, and $\cos z_m$ (see above) for the 20 points are calculated from the formulas below.

Calculation formulas:

1. There are made the equalities $\bar{x}_1 - x_0 = x_1$, $\bar{y}_1 - y_0 = y_1$,
 $\bar{x}_k - x_0 = x_k$, $\bar{y}_k - y_0 = y_k$,
 $\bar{x}_m - x_0 = x_m$, $\bar{y}_m - y_0 = y_m$,

where $i = 1 \dots 12$, $k = 1 \dots 16$, $m = 1 \dots 20$.

2. The ideal coordinates of the reference stars are figured:

$$\left. \begin{aligned} \xi_i &= \frac{\cos b_i \sin(a_i - a_0)}{\sin b_i \sin b_0 + \cos b_i \cos b_0 \cos(a_i - a_0)}; \\ \eta_i &= \frac{\sin b_i \cos b_0 - \cos b_i \sin b_0 \cos(a_i - a_0)}{\sin b_i \sin b_0 + \cos b_i \cos b_0 \cos(a_i - a_0)} \end{aligned} \right\} \quad (1)$$

3. By the method of least squares are figured the coefficients of the relationship between the measured and ideal coordinates for the reference stars $a, b, c, d, e, f, p, s, q, t$:

$$\left. \begin{aligned} \xi_i &= ax_i + by_i + c + px_i^2 + sx_i; \\ \eta_i &= dx_i + ey_i + f + qx_i^2 + tx_i \end{aligned} \right\} \quad (2)$$

For a check the machine delivers the residual errors in Eq. 2 $\Delta\xi_1$ and $\Delta\eta_1$, from the size of which we may judge the accuracy of the measurements and the presence or absence of errors in identifying the reference stars.

From Eq. 2 ξ_k and η_k are found by substituting x_k and y_k ; and from them α_k and δ_k by using the formulas:

$$\left. \begin{aligned} d_k &= \arctan \eta_k + \delta_0; \\ \tan(a_k - a_0) &= \frac{\xi_k}{\cos b_0 - \eta_k \sin b_0}; \\ \tan \delta_k &= \tan d_k \cos(a_k - a_0). \end{aligned} \right\} \quad (3)$$

Then from α_k and δ_k by the method of least squares are calculated the coordinates of the pole of the meteor's great circle A and $\sin R_k$, where R_k is the declinations of the points α_k and δ_k from the calculated great circle:

$$\cos \alpha_k + \sin \alpha_k \tan \frac{a_{PA}}{k=1 \dots 16} + \tan \delta_k \tan \frac{\delta_{PA}}{k=1 \dots 16} \sin \alpha_{PA} = 0, \quad (4)$$

$$\sin R_k = \sin \delta_k \sin \delta_{PA} + \cos \delta_k \cos \delta_{PA} \cos(\alpha_k - \alpha_{PA}). \quad (4a)$$

Similar calculations are also made for plate B, after which are determined the radian coordinates α_R and δ_R :

$$\left. \begin{aligned} \tan \alpha_R \tan \alpha_{PA} + \tan \delta_{PA} \sec \alpha_{PA} \tan \delta_R \sec \alpha_R &= -1; \\ \tan \alpha_R \tan \alpha_{PB} + \tan \delta_{PB} \sec \alpha_{PB} \tan \delta_R \sec \alpha_R &= -1. \end{aligned} \right\} \quad (5)$$

The following is also calculated

$$\cos Q = \sin \delta_{PA} \sin \delta_{PB} + \cos \delta_{PA} \cos \delta_{PB} \cos(\alpha_{PA} - \alpha_{PB}),$$

where Q is the angle between the meteor circles A and B at the radian.

Finding the coordinates for simultaneous points. By substituting x_m, y_m for each m of Eq. 2 ξ_m, η_m are calculated and from them α_{Am}, δ_{Am} .

From Formulas 5a - the analogue of Formulas 5 - are found the auxiliary values $\tan \alpha_m, \tan \delta_m \sec \alpha_m$:

$$\left. \begin{aligned} \tan \alpha_m \tan \alpha_b + \tan \delta_m \sec \alpha_m \tan \delta_b \sec \alpha_b &= -1; \\ \tan \alpha_m \tan \alpha_{Am} + \tan \delta_m \sec \alpha_m \tan \delta_{Am} \sec \alpha_{Am} &= -1, \end{aligned} \right\} \quad (5a)$$

where $\alpha_b = S - t_b$; from 5b are figured the coordinates α_{Bm}, δ_{Bm} of the point simultaneous to α_{Am}, δ_{Am} :

$$\left. \begin{aligned} \tan \alpha_m \tan \alpha_{Bm} + \tan \delta_m \sec \alpha_m \tan \delta_{Bm} \sec \alpha_{Bm} &= -1; \\ \tan \alpha_{PB} \tan \alpha_{Bm} + \tan \delta_{PB} \sec \alpha_{PB} \tan \delta_{Bm} \sec \alpha_{Bm} &= -1. \end{aligned} \right\} \quad (5b)$$

The distance of point m from point A is determined from the formula

$$\rho_m = \frac{\delta \cos \delta_b \sin(\alpha_{Bm} - \alpha_b)}{\cos \delta_{Am} \sin(\alpha_{Bm} - \alpha_{Am})} \quad (6)$$

and the height of this point relative to the horizontal plane of point A

$$H_m \text{ obs.} = \rho_m \cos z_m, \quad (8)$$

where $\cos z_m = \sin \delta_{Am} \sin \varphi + \cos \delta_{Am} \cos \varphi \cos (S - z_{Am})$. (7)

The zenith distance of the radian z_R is also figured.

Thus by combining the initial data and the results of our calculations we have a number of values for H_m obs. and τ_m corresponding to them.

Velocities and decelerations. The height $H_{obs.}$ presents itself in the form of a polynomial of the 4th degree:

$$H_{obs.} = a + b\tau + c\tau^2 + p\tau^3 + s\tau^4. \quad (9)$$

The parameters a, b, c, p, s for H_m obs. ($m = 1 \dots 20$) are discovered by the method of least squares.

From a, b, c, p, s are calculated the values of H_m calc. and the subtractions H_m obs. - H_m calc. are made; for all values of m the velocities and decelerations are figured by differentiating Formula 9 with respect to τ :

$$V_m = \frac{1}{\cos z_R} (b + 2c\tau_m + 3p\tau_m^2 + 4s\tau_m^3),$$

$$W_m = -\frac{1}{\cos z_R} (2c + 6p\tau_m + 12s\tau_m^2).$$

The machine delivers $\alpha_{PA}, \delta_{PA}, \alpha_{PB}, \delta_{PB}, \alpha_R, \delta_R; \cos z_R, H_m$ calc., H_m obs., H_m calc., $\cos z_m, V_m, W_m$, the residual declinations of Eq. 2 $\Delta\xi_A, \Delta\eta_A, \Delta\xi_B, \Delta\eta_B, \cos Q$, the values of a, b, c, p, s from Eq. 9 divided by $\cos z_R; \sin R_{kA}, \sin R_{kB}$.

As a check on the calculations they are carried out twice. The approximate amount of time spent on processing the photographs of one meteor used as a basis using the "Strela" computer is as follows:

choice of stars and transcribing their positions from the catalogues	4 hrs
measurement	2 hrs
preparation of the initial data for punching (filling the cards)	1 hr 30 min
punching and checking the cards	30 min
calculation	2.5 min
printing the results	<u>3 min</u>
Total	8 hr 6 min

Thus, preparing the initial data for the calculations and the calculations themselves on "Strela" take a little more than 2 hours.

At the same time no less than 50 hours are spent on processing the measurements when calculating by hand.

Using a "Strela" computer in the spring of 1958 part of the photographic meteor observations of the Stalinabad, Kiev, and Odessa observatories were processed in the MGU Computation Center.

I consider it my pleasant duty to thank Prof. Ye. Ya. Bugoslavskaya and Prof. G. S. Roslyakov whose advice helped me very much in carrying out the present work.

Supplement 1. The flow pattern and the programming of the calculations are set up in such a way that they permit us also to process negatives gotten from non-guided cameras — it is only necessary to insert the following on the initial data sheets: zero on the S line, $-t_b$ on the t_b line, and the hour angles $t_0, t_1 \dots t_{12}$ in place of the right ascensions $\alpha_0, \alpha_1 \dots \alpha_{12}$ of the reference stars.

Supplement 2. Flow pattern for transferring numbers to the base 60 to those to the base 2 (60 → 2)

"Strela" conducts trigonometric operations on angles expressed

abstractly and to the base 2. Since the initial data α and δ are given in the sexagesimal system — in hours, minutes, seconds of time and degrees, minutes, seconds of arc — it was necessary to find some means of changing α and δ into abstract measure in the binary system. The following algorithm was used in our program for that purpose.

If the angles are written in a semilogarithmic form placing the ordinate 02 before all numbers (angles), then mantissa d of angle α , expressed in degrees and parts of degrees — minutes and seconds of arc (or hours, minutes, and seconds of time) — may be expressed as

$$d = (b_1 10^{-1} + b_2 10^{-2}) \cdot (b_3 10^{-2} 6^{-1} + b_4 10^{-3} 6^{-1}) + \\ + (b_5 10^{-3} 6^{-2} + b_6 10^{-4} 6^{-2}) + (b_7 10^{-5} 6^{-2} + \\ + b_8 10^{-6} 6^{-2} + b_9 10^{-7} 6^{-2}),$$

where b_1, b_2, \dots are sexagesimal divisions of the number (angle), counting from left to right: b_1 represents tenths of degrees, b_2 — units of degrees, b_3 — tenths of minutes, etc.

In conformity with this, for angles expressed both in arc and time, when transposing $60 \rightarrow 2$ we used the algorithm

$(\dots (x_1 10 + x_2) 10 + x_3) 6 + x_4) 10 + x_5) 6 + x_6) 10 + x_7) 10 + x_8) 10 + x_9) 10^{-6} 6^{-2} 2^4$, where $x_1 = b_1 2^{-4}$ and b_1 is the 1-th decimal figure of the transposed number (the angle is written in the form of a decimal number!).

For transposing angles into abstract measure they are, as usual, expressed in degrees and multiplied by the multiplier $\frac{\pi}{2} \cdot \frac{1}{90}$; and when expressed in hours, by $\frac{\pi}{2} \cdot \frac{1}{6}$.

The $60 \rightarrow 2$ transposal program, included in the complete computational program, enables us to introduce the initial data for the angles directly into the machine in hours (degrees), minutes, seconds, and

fractions of seconds, written as follows:

$+0,234852425 \cdot 10^3$	}	instead of	$23^h 48^m 52^s, 425$	}
$+0,000001208 \cdot 10^3$		$00^h 00^m 01^s, 208$		
$+0,6538171 \cdot 10^2$		$+65^\circ 38' 17'', 1$		
$-0,0027134 \cdot 10^2$		$-00^\circ 27' 13'', 4$		

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